# Reliability Improvement and Optimal Placement of Remote Controlling Switches of Distribution Systems Using Tabu Search Algorithm

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***Abstract***

Nowadays, automation in the distribution systems has been widely developed. Remote control switches are of these new technologies employed in an unprecedented rate. Indeed, load management in feeders and loss reduction could be achieved via these switches. Though the optimal placement is significant, it might not be that easy and acquirable. On the other hand, reliability, as an important feature of distribution systems, is the salient objective of this research. In this paper, a new approach based on the importance of reliability is introduced to determine the optimal number and location of remote control switches in distribution systems to have minimum consumers out of service. The cost function makes compromise between the expense spent on switch installation on one side and the gained profit from their operation on the other side. Therefore, the best place for switches is chosen using Tabu Search Algorithm. Finally, the proposed algorithm is implemented on a standard test system to evaluate its capabilities.

***Keywords***

*Distribution System; Optimal Placement; Regional Switch; Reliability; Tabu Search Algorithm*

## Introduction

Naturally, distribution systems, as the largest part of power system, pay noticeable attention to reliability. Statistics validate that the main reason that makes consumers out of service is fault in the distribution system. Therefore, improvement in reliability can bring not only consumers satisfaction but also reduction in costs related to power cuts and consequently performance enhancement [Brown (2002)]. Generally, automatic switching devices are implemented in distribution systems for various purposes such as fault isolation, network reconstruction, reliability betterment, etc.

One of the most effective ways to improve distribution network reliability is to install switches with capability of remote control. Indeed, the switch automation might affect both speed and rate of success in load restoration. As a result, consumers are provided with a more reliable power supply. Distribution system automation is an intricate issue which has different sides that should be observed thoroughly. Both technical and economic feasibility aspects are taken into account for implementation. In practice, economic functions should cover profitability of the modified power system enhanced with remote switches. Such automated and smart grids lead to power quality improvement.

Generally, among numerous intelligent systems introduced through the history, many have been applied somehow on power systems [Aruldoss (2011) and Roy (2011)]. The main reason is that typical power networks are intricate and vast and also require accurate decision making units for proper operation. Therefore, artificial intelligent based approaches usually can be helpful. Although a variety of studies have paid to reliability enhancement through optimal placement of switches [Abdelaziz (2002), Celli (1999), Teng (2002), and Teng (2003)], using remote control switches has been less under consideration. Unfortunately, optimal placement in distribution systems is challenging due to numerous different choices that should be investigated technically and financially.

Since the system configuration is convoluted, the optimization procedure demands a huge amount of mathematical calculations [He (1999) and Teng (2003)]. In fact, the optimal placement process cannot be obtained using conventional methods. Therefore, some heuristic approaches are employed such as simulated annealing, particle swarm optimization, Pareto algorithm, and genetic algorithm [Bland (1991), Moradi (2005), and Shieh-Shing (2013)]. There are various presented techniques to solve multi-objective functions in distribution system design; for instance: the non-dominated sorting genetic algorithm and strength Pareto evolutionary algorithm in [Fletcher (2007)], and also an innovative technique which differentiates the non-dominated multi-objective solutions with regard to the concurrent optimization of the fuzzy economic cost, fuzzy reliability rate based on Tabu search in [Ramirez-Rosado (2001)]. Furthermore, a recent research introduced a multi-objective reactive tabu search algorithm to enhance reliability in developing power distribution networks [Cossi (2012)].

In this paper, the Tabu Search Algorithm (TSA) is adopted to determine the best place for switches in the distribution system. A simple instance here can be helpful to clarify the issue and usage of modern heuristic techniques as follows.

A typical distribution system is assumed with 22 recommended positions for switches, but because of investment limitations, only 12 choices have feasibility. For this case, the available solutions are the combination of 12 out of 22 (C(12, 22)), equal to 646646 different configurations. Furthermore, all possible solutions should be assessed through financial aspect that demands hundred days to recognize the optimal choice. It is clear that this policy may not be suitable for running systems. Therefore, heuristic search methods are preferred to obtain the optimal solution in few minutes [Teng (2003)].

Considering all above-mentioned, the role of regional switches in power distribution systems is explained in the second section. The third section is allotted to the problem formulation. Afterwards, the Tabu Search Algorithm and its structure are discussed in section IV. The following section aims to develop an optimal placement algorithm for remote control switches. In section VI, a real standard system is studied and the performance of algorithm is examined in practice. Finally, section VII tries to sum up the issue and draw a conclusion.

## Regional Switches in Radial Distribution Systems

Considering the configuration of radial distribution networks, if one device goes out of service, all subscribers after that point will be lost. Besides, the consumers have to wait out of power during maintenance and repair period. Hence, the consumers located in the end of feeders have less reliability and experience higher cut out rate. In fact, if the power system takes another policy for the equipments under repair while some downstream loads are energized through bypass or main feeder, not only subscribers' satisfaction level ascends, but also that would be possible to sell energy during the repair time and to reduce total loss in this period [Moradi (2005)]. Regional switches, as a practicable solution, may be installed in both ends of a branch in a distribution system and might follow two different strategies.

The first is not to put normally open switches in the end of main feeders. In this situation, if a device has problem, the nearest regional switch can cut out the power and let the impaired point be investigated. Hence, there is no need to disconnect the circuit breaker and subsequently, the load shedding area would be shorter. In fact, this strategy provides some loads with one way energizing through the main feeder.

The second is that this scheme includes normally open switches. In this case, some loads can be energized via both main and auxiliary feeders in urgent occasions. In other words, normally open switches facilitate power supply in some areas. For instance, an impaired device is assumed located between two regional switches. Vividly, the two switches should cut off the line for repair operation. Meanwhile, the normally open switches could provide electricity for the affected loads through the bypass way.

## Problem Formulation

The objective function aims to minimize the costs due to load shedding via optimal placement and rearrangement of switches in distribution feeders. Therefore, the objective function related to the out of service power supplies should be minimized.

ECOST function takes the effects of system structure, cut out time, load alteration, unpredicted faults, and different load types into consideration.

$$ECOST = \sum_{j=1}^{nj} \sum_{k=1}^{nk} L_k . C_{jk}(r_j) . \lambda_j \qquad (\$/yr) \qquad (1)$$

Moreover, the costs due to Expected Energy Not Supplied (EENS) should be considered and the function is defined as follows:

$$EENS = \sum_{J=1}^{nj} \sum_{k=1}^{nk} L_k . r_j . \lambda_j \qquad (KWh / yr) \qquad (2)$$

where $nk$ indicates the cut out locations due to $j$ th event; $nj$ is the number of events; $L_k$ is off-grid loads at point $k$ ; $r_j$ is the average time of being out of service during event $j$ ; $\lambda_j$ is the annual fault rate; and $C_{jk}$ is the cost of power not sold per kilowatt.

Considering the expense related to cut out time (ECOST), reliability, and investment, makes it more justifiable to have an optimization method to determine the number and location of regional switches. It should be noticed that these equipments, as the down side, demand a remarkable investment at first. A recommended policy is to start installing switches in two ends of each branch and calculating the corresponding ECOST. If the predicted cost meets the invested value in a given period, it might be rational to perform the plan. Otherwise, the succeeding steps should be executed:

1. All available positions to install new switches should be recognized (maximum number of switches that can be used)
2. One single switch should be placed in all different positions in turns; then, the regarding ECOST for each mode should be calculated. Afterwards, comparing all possible choices, the best location for the switch would be obtained.
3. The previous step should be carried out for all positions and switches; subsequently, the best place for switches would be determined.
4. Considering the above algorithm, calculation of all possible positions for switch installation would be burdensome due to numerous choices in distribution systems. Hence, utilizing TSA could be a successful approach to optimize switch places and to minimize ECOST.

## Tabu Search Algorithm

Tabu Search Algorithm, introduced by Glover in 1989, is a heuristic search method, very similar to the human memory process, to find the best solutions in optimization problems. In this method, a rewritable memory is used to hold the search history which would be adopted as a new solution in the search space for the next steps. Later, Bland and Dawson exploited TSA for optimization problems and obtained remarkable outcomes. Overall, TSA can be divided into two major components: Tabu list and aspiration criteria. TSA algorithm starts with different initial solutions and keeps developing until the best solution is attained for each step. Meanwhile, solution values could alter between different steps. TSA is amended by the gathered information during the search. As a matter of fact, returning to solutions that have already been traversed and moving to similar solutions are forbidden; therefore, the algorithm can leave the local minimum to find a global optimal solution. After saving the best solutions of all steps, searching process is halted and the best one is extracted among current solutions. The comprehensive block diagram illustrates the whole procedure in Fig. 1 [Glover (1989) and Glover (1990)].

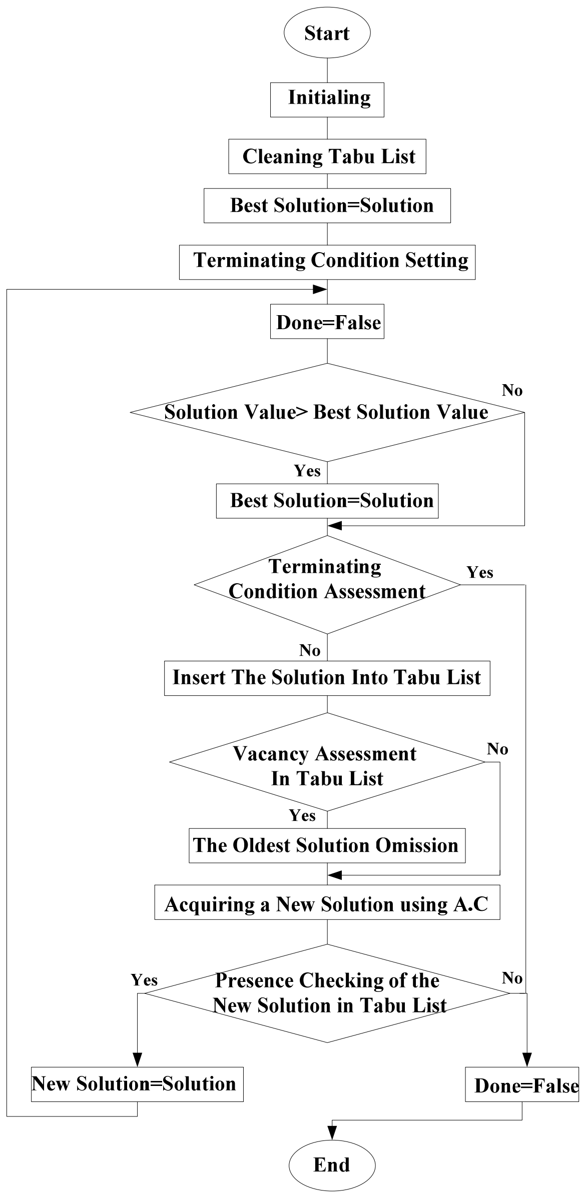


FIG. 1 TABU SEARCH ALGORITHM FLOWCHART

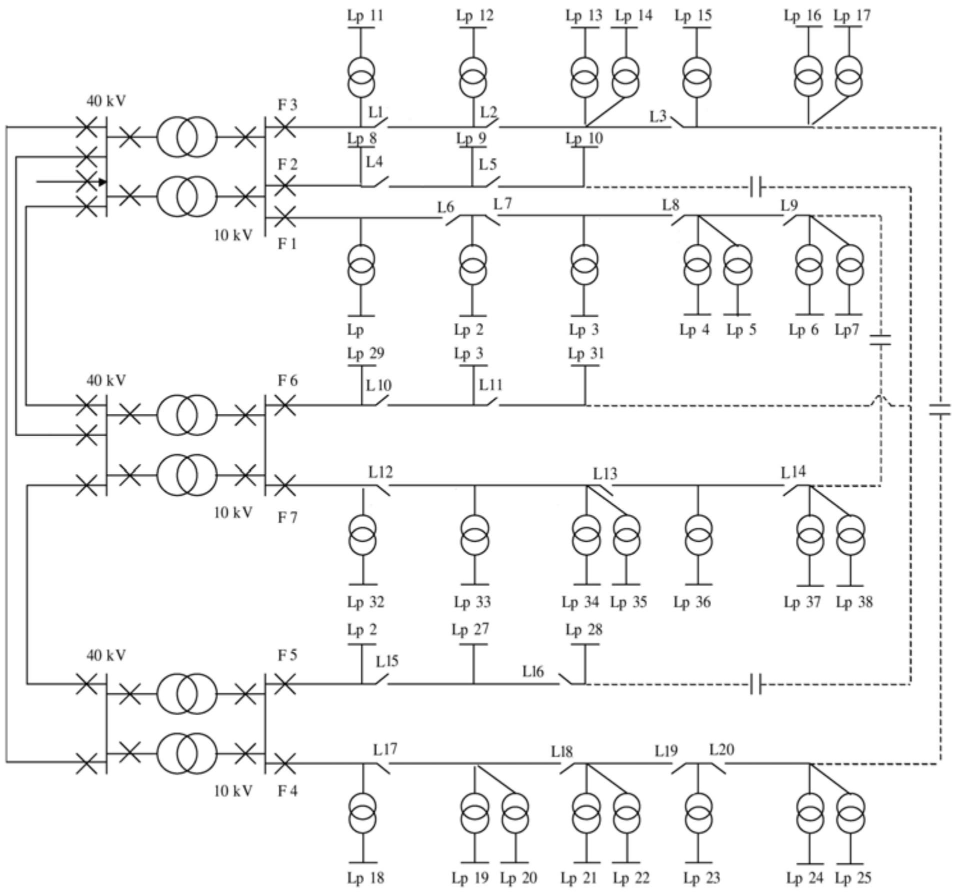


FIG. 2 THE STANDARD TEST SYSTEM BUS 4-RBTS

## Tabu Search Algorithm for Optimal Placement

Optimal placement procedure using TSA is as follows:

First: regarding acceptable combinations, a good starting point is selected and ECOST is calculated based on equation 1. The answer is considered as the best solution if the total cost meets investment and other expenditures condition.

Second: the next combination is evaluated and the corresponding ECOST is obtained.

Third: the recent cost function should be compared with the best solution.

(A) If the recent cost function is less than the best solution, it goes to the Tabu list and hereinafter it would be considered as the best solution. However, in cases that Tabu list if full, the greater amount should be taken out of list.

(B) If the ECOST value is greater than the best solution, this item goes to the Tabu list; but if there is not any blank place, the greatest ECOST would be off the list.

Fourth: the previous steps are repeated until the halt criteria are achieved.

## Simulation Results

The proposed method is implemented on the standard test system (Fig. 2) to enhance the reliability indices as a result of optimal placement for regional switches. The mentioned system includes 38 load points and 20 switching places. The optimization problem was accomplished through Matlab/Simulink software. The whole algorithm ran for five times to insure about its efficiency.

All information required for algorithm is extracted from [Allan (1991)] in detail. The list includes network structure, load data, types of automation equipment, consumers' information, and delay reports.

In this research, the cost of equipping each switch with the remote control devices is 10 dollars, calculated in economic data. Moreover, $C_{jk}$ is \$0.038, indicating the costs associated with the period when the power is out. The initial investment is assumed \$700 and the number of iterations is 100.

This paper develops the survey through two approaches:

Case I: employing circuit breakers and switches without normally open auxiliary ones.

In this way, all single positions are assessed and the corresponding results listed in Table 1 indicate optimum switch numbers with regard to the economic aspect and minimum interruptions. Altogether, for 10 switches, the best positions would be location 1 to 9 as well as 14. In this situation, ECOST and EENS are equal to 478.58678 $/yr and 10062.81 KWh/yr.

TABLE I RELIABILITY INDICES FOR CASE I

| **Number of switchs** | **ECOST($/yr)** | **EENS(KWh/yr)** |
|---|---|---|
| 1 | 518.15442 | 11024.59 |
| 2 | 521.56666 | 11091.07 |
| 3 | 547.21362 | 11642.482 |
| 4 | 555.12275 | 11811.125 |
| 5 | 616.34219 | 13113.005 |
| 6 | 478.30392 | 11304.84 |
| 7 | 494.20502 | 11233.29 |
| 8 | 506.87851 | 11313.645 |
| 9 | 495.48508 | 10760.66 |
| 10 | 478.58678 | 10062.81 |
| 11 | 617.80046 | 13473.17 |
| 12 | 743.72174 | 16533.73 |
| 13 | 847.41834 | 19009.43 |
| 14 | 969.2927 | 21963.665 |
| 15 | 1007.15498 | 22706.71 |
| 16 | 1059/10546 | 23820.67 |
| 17 | 1112.75207 | 24979.265 |
| 18 | 1152.89139 | 25782.405 |
| 19 | 1154/10936 | 25560.88 |
| 20 | 1198/63373 | 26479.835 |

Case II: employing circuit breakers and switches as well as normally open auxiliary ones.

TABLE II RELIABILITY INDICES FOR CASE II

| Number of switchs | ECOST($/yr) | EENS(KWh/yr) |
|---|---|---|
| 1 | 726.616 | 187 |
| 2 | 622.5172 | 339.4 |
| 3 | 631.57925 | 577.875 |
| 4 | 622.17216 | 330.32 |
| 5 | 634.51285 | 655.075 |
| 6 | 614.6816 | 133.2 |
| 7 | 616.2586 | 174.7 |
| 8 | 614.72017 | 134.215 |
| 9 | 614.3776 | 125.2 |
| 10 | 617.7805 | 214.75 |
| 11 | 622.68288 | 343.76 |
| 12 | 640.4912 | 812.4 |
| 13 | 641.2759 | 833.05 |
| 14 | 616.9312 | 192.4 |
| 15 | 622.4431 | 337.45 |
| 16 | 631.9849 | 588.55 |
| 17 | 622.5552 | 340.4 |
| 18 | 636.05869 | 695.755 |
| 19 | 615.03272 | 142.44 |
| 20 | 618.15442 | 244.59 |

Performing this algorithm yields results shown in Table 2. Herein, the cost associated with each normally open switch, including its installation, is assumed $600. Regarding Table 2, the optimum number of switches is 9 and the best positions for switch installation are locations 1 to 7, 9, and 14. In this case ECOST and EENS are about 614.3776 $/yr and 125.2 KWh/yr. Similarly, the optimal places for switch installation are listed in Table 3.

TABLE III OPTIMAL LOCATION FOR SWITCH INSTALLATION

| | |
|---|---|
| **Case I** (n=10) | S1,S2,S3,S4,S5,S6,S7,S8,S9,S14 |
| **Case II** (n=9) | S1,S2,S3,S4,S5,S6,S7,S9,S14 |

## Conclusions

Automation of switches, a crucial function in distribution systems, may work as a technique to improve reliability. Considering different effective elements in determining the optimum number of swatches, the optimization problem could be burdensome. In this paper, the feasibility of reliability improvement using switch optimization in distribution feeders is surveyed.

The optimization is developed based on the Tabu Search Algorithm as a successful approach. Afterwards, some numerical studies were carried out on a standard test system to assess the performance and effectiveness of the new method. Simulation results confirm that the proposed technique is powerful and brings satisfactory achievements. The proposed model can be implemented in software as a handy way to economically determine locations where could be remote control points.

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